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14. ABSTRACT
The goal of this effort was to design, develop, and acquire a well-equipped platform for experimental evaluation of intelligent, mobile sensor network application to enhance our research. The equipment purchased included three Pioneer all-terrain robots as well as several smaller, more limited robots. Also acquired was a collection of off-the-shelf sensors and sensor kits for large scale experiments including Crossbow Technology Inc.'s Mote kits (which include MICA motes, sensor and acquisition boards, and development tools), digital cameras, and interface boards (e.g. Crossbow's gateways). Finally, several laptop and handheld computers that will be used as processing nodes and/or to act as controllers/monitors for the robot and sensor systems were also purchased. The purchased equipment has already been used in pursuit of several projects including the development of several mobile sensor networking systems, model-driven tools for developing sensor networks, and a DoD project to demonstrate single users to control robot teams.

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Final Report

A Test-bed for Intelligent, Mobile Sensor Applications

Grant Number: FA9550-07-1-0294

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June 23, 2008

Abstract

The goal of this effort was to design, develop, and acquire a well-equipped platform for experimental evaluation of intelligent, mobile sensor network application to enhance our research. For example, evaluating a human-controlled, intelligent mobile sensor network requires a large-scale, heterogeneous sensor network consisting of numerous sensors on mobile and fixed platforms. To address these issues, we acquired 3 all-terrain robots, several Crossbow Mote Kits, Crossbow Stargate gateways, and a collection of sensors, handheld devices, laptops and servers. The personnel to develop and maintain the experimental platform is being funded by a K-State Targeted Excellence grant to advance sensor systems research, which provides $1,500,000 over three years starting July 2006.

Specifically, the goals of the platform are to:

- Significantly enhance the quality of existing/future projects by providing a flexible infrastructure to execute large-scale demonstrations,
- Allow demonstration of the results of research on large-scale, end-to-end sensor applications addressing future DoD needs,
- Foster collaborative and technology transfer activities, and develop stronger relationship with DoD laboratories and members of the defense community,
- Enhance efforts to train students in intelligent, mobile sensor systems research, and create a stronger graduate student base required to complete large projects.

The equipment purchased included three Pioneer all-terrain robots as well as several smaller, more limited robots. We also purchased a collection of off-the-shelf sensors and sensor kits for large scale experiments including Crossbow Technology Inc.'s Mote kits (which include MICA motes, sensor and acquisition boards, and development tools), digital cameras, and interface boards (e.g. Crossbow's gateways). Finally, we purchased several laptop and handheld computers that will be used as processing nodes and/or to act as controllers/monitors for the robot and sensor systems. All in all, this grant has given us a broad range of capabilities with which to build a large variety of static, adaptive, and mobile sensor network systems.

As the goal of this award was to acquire equipment to build an infrastructure for enabling future and existing research projects, we have already used the equipment in pursuit of several projects including the development of several mobile sensor networking systems, model-driven tools for developing sensor networks, a US Marine Corp project to allow single users to control teams of robots, and the training and development of several graduate students.

Equipment Purchased

Table 1 shows the equipment purchased with this grant. A major part of the equipment purchase was three Pioneer all-terrain robots that will be used to demonstrate mobile sensor networking technology outdoors, over fairly large distances. Each robot is equipped with an on-board computer for completely autonomous operation, a set of sonars and a laser range finder for accurate map building and obstacle avoidance capabilities, and a camera for visual detection. The robots can communicate with each other, human users, and other system components via a built-in wireless communication capability. In addition, add-on GPS units were bought to integrate with each robot to provide accurate navigation. Two of the three robots were outfitted with a gripper/robotic arm to allow the robots to manipulate their environment.

In addition to the three all-terrain robots, we purchased 15 SRV-1 Blackfin Mobile Robots, 2 Acroname Garcia Robots, and 13 Epuck Robots. These robots are much smaller and more limited. These were purchased in lieu of a 4th Pioneer as described in the proposal. These robots can be used alone in doors or in conjunction with the Pioneers. Most have on-board computers, video camera, and communication capabilities.

In addition to the robots, we also purchased several laptop and handheld computers that will be used as processing nodes and/or controllers/monitors for the robot and sensor systems. The laptops and desktop systems will be used to develop programs for the robots and sensor systems as well as to act as high-power data fusion nodes during experiments. We also purchased a standalone computer with 2 terabyte disk drive for backing up images of each robot and sensor configuration at various points during the research process.

We also purchased a collection of off-the-shelf sensors and sensor kits for large scale experiments. Specifically, the purchase included Crossbow Technology Inc.'s Mote kits (which include MICA motes, sensor and acquisition boards, and development tools), digital cameras, and interface boards (e.g. Crossbow's gateways). These sensors and sensor kits can run independently or attached to the robots. We have already demonstrated integration of the Pioneer robots with the MICA mote sensor boards.

All in all, we this grant has given us a broad range of capabilities with which to build a large variety of static, adaptive, and mobile sensor network systems.

Table 1. Equipment Purchased

Item	Quantity	Cost
Pioneer 3-AT Mobile Robot Base Pioneer	3	$17,985
Pioneer 3-AT Indoor Wheels Set	3	$1,125
Pioneer 3-AT On-Board COBRA B Computer Onboard 1.6 GHz VERSALOGIC PC	3	$11,325
Pioneer 3-AT Windows XP Install & test Plug-N-Play ready	3	$2,160

Pioneer 3-AT PTZ Tracking/Surveillance/Vision System	2	$7,490
Pioneer 3-AT PTZ Under-Mount Tracking Surveillance Vision	1	$4,030
Pioneer 3-AT Laser Range Finder Mapping & Navigation System (SICK LMS200)	3	$22,485
Pioneer 3-AT Gyroscopic Correction System Angular Rate Gyro w/ software	3	$840
Pioneer 3-AT Sonar Ring, P3-AT	3	$2,535
Pioneer 3-AT Arm 5 dof Arm plus 1dof gripper	1	$4,795
Pioneer 3-AT 2-dof Gripper 2-dof Gripper	1	$1,990
Pioneer 3-AT 1Mb Wireless Ethernet/MINI-PCI 11 Mb fixed channel	3	$2,835
Pioneer 3-AT High-Capacity Charger, 5x,110V 5amp, 100-110V	9	$2,520
Pioneer 3-AT POWER CUBE Slide-in Power Cube & extra batteries	2	$1,740
Holux GR-213 USB SiRF Star III GPS Receiver(GR-213) (SiRF III)(WAAS)	7	$350
Pioneer 3-AT Motherboard	1	$1,800
SRV-1 Blackfin Mobile Robot	15	$6,724
Epuck Robots from RoboticRoadNarrows	13	$14,400
Acroname Garcia Robots	2	$4,600
Bountiful BWRG1000 WiFi Long Range Router	1	$300
Handheld Controllers	2	$1,206
Robot backup server	1	$2,731
Sensor boards and gateways from Crossbow	100+	$25,740
Dell Laptops	6	$16,222
Samsung Q1 Ultra PC	2	$3,400
Desktop machines	8	$11,788
Motion Computer Tablet LE1700	1	$2,596
Identec RFID Kit	2	$3,060
Easysen proximity sensors	20	$5,794
Lego Nxt Kit	2	$600
Acrom Zypad 1100 PC	1	$2,500
HP iPAQ 2790/210/5910/6920 & accessories	28	$17,215
Sun Spot sensor kits	4	$1,200
Socket Mobile SOMO 650-M Handheld	2	$1,794
NCD Zigbee Relays	10	$2,300
Trimble Juno Handheld	3	$3,600
Asus M900 Tablet PCs	2	$1,800
Panasonic Network Camera BB-HCE481	1	$782
		$216,357

Research/Educational Projects

The goal of this award was to acquire equipment to build infrastructure for enabling existing research projects. The following are some of the activities we have engaged in or are starting with the help of this infrastructure.

Mobile Sensor Network Systems

We are using robots and motes to develop several mobile sensor network (cooperative robots combined with sensor networking) applications. The first is a fire detection system that uses distributed motes to detect heat and light while the robots are used to take additional reading to verify the stationary sensors, replace failed sensors, and to make reading where stationary sensors do not exist. The second application is a multi-robot search application (using the robots and motes purchased from this grant) to demonstrate our approach to controlling multirobot teams by a single operator. The final application was the development of a pursuer-evader application which demonstrated the working of a heterogeneous network with different types of communication links.

Model-driven Tools for Sensor Networks

We are also developing model-driven tools and techniques to design large-scale, sensor network applications. These tools allow automatic code generation, configuration, deployment and optimization of embedded systems software. We are targeting the modeling and code generation capabilities for the experimentation platform consisting of sensor and processor boards from Crossbow using the nesC component model and TinyOS operating system. In the past year, we have extended our Cadena software specification environment to allow specification and development of applications using the nesC component model. We have also developed tools for remote deployment, control and visualization of sensor applications. A significant amount of time was devoted to extend the TOSSIM simulation framework to allow the simulation to be externally controlled and create a simulation environment for the application to interact with.

Training and Development

We have involved a number of graduate and undergraduate students on research using the instrumentation acquired under this project as described in the following:

(1) We have introduced a new multidisciplinary course on sensor network implementation which will use the equipment to implement realistic sensor applications. This course was offered in Spring 08.

(2) The grant has allowed several graduate students to start working with and programming on Active Media Pioneer III all terrain robots as part of MS level projects

or theses. In addition, several other graduate students are working with the motes and learning about sensor networks.

Controlling Robot Teams

By far the most advanced use for the equipment purchased by this grant is a US Marine Corp/M2 Technologies Corporation project to build a cooperative robotic system that can be controlled by a single operator. The project uses *organizational control* allows the operators to focus on how the team approaches a problem instead of directing the team in how to solve the problem. In organizational control, the operator interacts with a team of robot concentrating on team/organizational concepts such as organizational goals and the assignment of robots to roles in the organization. The initial goal of this research is to develop a mechanism to allow operators to control robot teams using organizational control and to assess the effectiveness of that approach. The scenario chosen to demonstrate this technology was an Improvised Explosive Device (IED) monitoring and detection system for major supply routes.

In the scenario, a team of robots is used to monitor an area for IEDs and report back to the human supervisor if something suspicious is found. The robots involved are a set of heterogeneous P-3AT robots, each possessing different sensors and effectors. There are four important capabilities: the ability to localize (using GPS), the ability to detect environmental changes (using robot sonar and laser range finders), the ability to identify IEDs (using cameras), and the ability to dispose of IEDs (using robot gripper/arms). The number of robots (n) is variable in our IED detection system (currently we are using 3 and are planning on moving to 6 total). The area is decomposed into smaller areas for patrolling by the robots. When environmental changes are detected, these changes are flagged for identification. Robots that are capable of identifying IEDs (which may be the same robot that detected the change) attempt to identify the object as inert or an IED. When unsure, the human operator is then tasked to help with the identification. When an IED is confirmed, a robot capable of disposing of IEDs is tasked with disposal.

Our first goal in this project was to see if the team could autonomously organize itself and reorganize itself when a failure occurred. In December 2007, we conducted our first field experiment to demonstrate our progress toward implementing the IED scenario. Our goal was to demonstrate (1) the ability of the team to organize and divide areas to be patrolled among 3 robots, (2) the ability of individual robots to patrol their assigned areas, (3) the ability of the team to recognize when a robot had failed and reassign its search area, (4) to demonstrate the patrolling of newly assigned areas, and (5) to display the organizational state to the operator. Essentially, we met with success in all four areas. Based on the results of the field experiment, we are currently enhancing and developing new capabilities such as:

- Advanced communications - extend communications to be able to use UDP for greater range/reliability.
- GPS integration - integrate new GPS sensors into Location capability

- Gripper integration – to allow robots to pick up objects in the environment
- Camera – integrate a vision capability to detect objects of various types and colors

Publications

Efficient Synchronization in Message Passing Systems, G. Singh and Ye Su, to appear in International Conf on Advanced Information Networking and Applications, March 2008.

A Model-driven Approach for Data Collection in Sensor Networks, to appear in International Conference on Parallel and Distributed Computing and Networks, Feb 2008

Scott A. DeLoach. Organizational Model for Adaptive Complex Systems. in Virginia Dignum (ed.) Multi-Agent Systems: Semantics and Dynamics of Organizational Models. IGI Global: Hershey, PA (in press, 2008).